Monitoring of Contaminants in Delaware Street Sweeping Residuals and Evaluation of Recycling/Disposal Options

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Abstract: DelDOT's street sweeping program recently was upgraded, and the amount of waste generated by these operations has increased significantly. Our monitoring program includes physical/chemical analyses of sweeper wastes in order to assess the effectiveness of street sweeping as a stormwater best management practice and to determine disposal and/or recycling options for these residuals. We have analyzed samples from piles of stored sweepings and directly from sweeper hoppers. Major contaminants detected were heavy metals, petroleum hydrocarbons, PAHs and phthalates. Bacteria and nutrient levels also were high in some of the wastes. Currently DelDOT's street sweeper wastes are taken to the Delaware Solid Waste Authority's landfills for disposal. Results of the monitoring program are helping us to explore alternative means of dealing with the large quantity of wastes generated that are more environmentally friendly and less costly.

Keywords: sweeper wastes, street sweeping, street cleaning, road cleaning residuals, stormwater BMPs

Introduction:

Regular cleaning of streets and storm sewers is a widely used stormwater quality Best Management Practice (BMP). Street sweepers are used to remove litter, debris and dirt from pavement surfaces before they are captured in runoff. Recent studies suggest that frequent sweeping can reduce levels of pollutants in urban runoff (Sutherland and Jelen, 1997). National Pollutant Discharge Elimination System (NPDES) permit requirements for urbanized areas and promulgation of Total Maximum Daily Load (TMDL) regulations have prompted many state and local governments to upgrade their street cleaning programs. A result of more intense street cleaning efforts is a significant increase in the amounts of sweeping wastes that are generated and must be managed and disposed of.

The Delaware Department of Transportation (DelDOT) maintains nearly 90% of the roadways in the state. Our street sweeping program includes the roadways, shoulders, intersections, and toll plaza lanes. As part of the requirements of DelDOT's NPDES Phase I and Phase II stormwater permits, the sweeping programs in New Castle County and parts of Kent County were upgraded in frequency, and older mechanical sweepers are being replaced gradually with newer regenerative air vacuum sweepers (Figure 1a). The vacuum type sweepers capture smaller particle sizes and, presumably, remove more contaminants from the roadways (Sutherland and Jelen, 1997). The roadways within the permitted areas currently are swept on the following cycle: roads with Average Daily Traffic (ADT) greater than 20,000 ("primary" roads) are swept 4 times a year, roads with ADT between 5,000 and 20,000 ("secondary"roads) are swept 2 times a year, and roads with ADT less than 5,000 ("tertiary" roads) are swept once a year.

Our monitoring program includes sampling and physical/chemical analyses of sweeper wastes in order to help assess the effectiveness of street sweeping as a BMP. The sweeper waste monitoring program is designed to determine (1) appropriate disposal and/or recycling options for DelDOT street sweeper waste; (2) how much pollution is removed by sweeping; (3) optimum frequency and timing of sweeping on Delaware roadways; and (4) which DelDOT roads receive most benefit from sweeping.

Since 2003 we have collected and analyzed samples from piles of sweepings held at DelDOT maintenance yards and from street sweeper hoppers immediately after collection from the roads. This paper describes the results of the monitoring program.

Methods

Stored Waste Piles

On June 10, 2003, we sampled two stockpiles of sweepings held at DelDOT's Chapman Road maintenance yard near Newark to establish what contaminants are present and to determine what disposal and/or recycling methods are appropriate for this waste. One of the piles consisted of sweepings that had been sifted using a Screen-All CV-40-D mechanical screener to remove gross pollutants and litter. Samples were collected from a variety of places throughout both piles representing varying ages of wastes (up to 2 years old), as well as varying degrees of exposure to rain and weathering (inside vs. outer edges of piles).

The samples were analyzed for: inorganics, including chloride and heavy metals; 46 volatile organic compounds; 89 semivolatile organics, including polycyclic aromatic hydrocarbons (PAHs); 14 PCB congeners; pH; nutrients; fecal coliform bacteria; and particle size distribution.

Three composite samples of screened sweeper wastes were also analyzed in April, 2005, for total petroleum hydrocarbons (TPH), BTEX, and Toxicity Characteristic leaching Procedure (TCLP) metals, semivolatiles, pesticides, herbicides and volatiles.

Collection from Hoppers

During 2004 and 2005, our monitoring focused on comparison of wastes collected from primary, secondary, and tertiary road types (corresponding to the 4:2:1 annual frequency of sweeping established under the DelDOT NPDES permit program). Each of three regenerative air sweepers was assigned to collect sweepings from one of the road types. Samples were collected only after a minimum 72-hour dry period, and only roads that had not recently been cleaned were swept for the sampling event. Upon return to the maintenance yard, the sweeper hoppers were emptied onto the ground, and ten samples were collected randomly from the contents of each hopper for physical and chemical analysis. This sampling took place approximately quarterly. Because the major contaminants detected in our initial studies were metals and hydrocarbons, the parameters for which the sweepings are analyzed were narrowed so that more replicates could be analyzed. Samples were analyzed for metals, PAHs, total petroleum hydrocarbons (TPH), nutrients, chloride, and grain size. For analyses of particle size distribution, three replicates were measured, except when the nature of the sample (e.g., primarily leaves) precluded analysis.

Results and Discussion

Stored Waste Piles

Street sweeping wastes can be extremely variable in types and levels of pollutants. Contaminants vary depending on highway design, surrounding land use, traffic patterns and volume, illicit discharges, accidental spills, rainfall patterns, maintenance activities, and frequency of cleaning (Gupta et al., 1981). Street waste can contain high sediment loads, oil and petroleum products, pesticides, fertilizers, bacteria, metals and other toxic materials. The pollutants removed from road surfaces by sweepers are primarily those that are attached to particulates. The constituents of concern most commonly mentioned in connection with street sweeping wastes are petroleum hydrocarbons, PAHs, and heavy metals. The more efficient street sweeping is at collecting fine particles, the higher its likely contaminant content.

Table 1 summarizes the chemical analyses of samples taken from sifted and unsifted sweeper waste stockpiles. Only those compounds that were detected in the samples are listed.

The main contaminants detected in both waste piles were metals and PAHs. Both are commonly found as pollutants in roadway runoff (Dierkes and Geiger, 1999; Gupta et al., 1981; Sansalone and Buchberger, 1996; Tuháčkov et al., 2001). Four different phthalate compounds were detected. Phthalates are used industrially as plasticizers, and bis(2-ethylhexyl) phthalate is the most common of these. The large amount of plastic trash and debris in the sweeper wastes most likely is the source of the phthalate compounds. Methyl acetate, a solvent commonly used in paints and coatings, was the only volatile organic contaminant detected in any quantity. It is also a component of fuel system cleaners and additives.

We hypothesized that the levels of particulate-associated pollutants such as metals would be greater in the sifted waste pile, due to the larger relative surface area of smaller particles. However, in general, no significant differences were found between contaminant levels from the unsifted and sifted piles (by t-test and Mann-Whitney rank sum test, $p<0.05$). Measurement of particle size distribution in each pile showed little overall difference in grain size between the two piles. In fact, the screener removed only the largest particles and trash from the waste. Methyl acetate levels were significantly higher in the unsifted pile ($p=0.008$), and phthalates were detected more often. This may reflect the greater amount of trash present in the unsifted wastes.

Results of leachability analyses are presented in Table 2. Petroleum hydrocarbons (TPH) were consistently high in all samples. TPH levels greater than 1000 mg/Kg result in the waste material being rejected by the Delaware Solid Waste Authority for clean landfill cover. All TCLP levels were below regulatory limits.

Comparison of Road Types

Models developed by Sutherland and Jelen (1997) show that sweeping has differing effectiveness in reducing suspended solids in runoff on different street types. An evaluation of street sweeping effectiveness in the City of San Jose, California, found that roads with high ADT volume were significantly dirtier than average (Woodward-Clyde Consultants, 1994). Shrake et al. (2003) investigated the impact of traffic congestion on stormwater runoff quality and found no significant differences in constituent means for congested and free-flowing traffic sites, except on roadway segments with relatively low ADT.

The results of our analyses of sweepings collected from roads of differing ADT levels showed no clear pattern in the distribution of particle sizes collected from the different road types. The majority of particles in sweepings from all three road types ranged from 0.1 to 5 mm in diameter.

The levels of contaminants in sweepings measured in our study (Figures 1 and 2) for the most part were comparable to those found by other investigators (Brinkmann et al., 1999; Liebens, 2001; Townsend et al., 2002; Woodward-Clyde Consultants, 1994). In almost all cases, the levels of metals and hydrocarbons in the DelDOT sweepings were well below the U.S. EPA Region III risk based concentration (RBC) limits for both industrial and residential soils. However, concentrations of several PAHs – benzo(a)anthracene, benzo(b)fluoranthene, benzo(a)pyrene, and indeno(1,2,3-cd)pyrene – did exceed the residential soil RBC.

In our study, the differences between contaminant concentrations from the three road types with differing ADT volumes generally were small and not statistically significant (Repeated Measures ANOVA on Ranks, $p>0.05$). Major exceptions were: a few metal species such as chromium and zinc (Figure 1), which in general were highest on primary and secondary roads; nutrients, particularly nitrogen (Figure 2), for which concentrations from subdivision (tertiary) roads were greatest in the winter months ($p<0.001$); and petroleum hydrocarbons (TPH) (Figure 2), which was highest on primary and secondary roads ($p<0.002$).

The differences observed in nutrient content of the sweepings from different road types can be explained by the fact that wastes collected from subdivision streets in late fall and early winter seasons consisted mostly of fallen leaves and tree debris, while those from primary roads were largely sand, gravel and similar particulates. Sweepings from secondary roadways typically consisted of a mix of dirt and organic matter.

As anticipated, heavy metals and petroleum hydrocarbons tended to occur in higher concentrations in sweepings from the roadways with higher traffic volumes. These pollutants are derived primarily from exhaust microparticles, tire wear, oil and fuel leakage, and pavement degradation. Other studies have shown that streets with the highest traffic loads have the greatest impact from these contaminants on roadside soils and groundwater (Dierkes and Geiger, 1999). PAHs also are found routinely in highway runoff (Smith et al., 2000) and in soils next to high-traffic roads (Dierkes and Geiger, 1999; Tuháčkov et al., 2001). In addition, daily wear and tear of pavement by traffic and weather results in asphalt particles being picked up by the street sweepers.

Conclusion

The Delaware Department of Transportation is responsible for maintaining 89% of the more than 12,500 lane miles of roads in Delaware. Municipalities are responsible for the other 11%. Delaware is one of only a few states with this high percentage of public roads under DOT jurisdiction. DelDOT's jurisdiction includes everything from the I-95 interstate highway that runs through New Castle County, to residential streets and rural roads.

Maintenance of this amount of street and highway surfaces generates a large quantity of solid waste. Currently DelDOT's street sweeper wastes are stockpiled at maintenance yards and then taken to the Delaware Solid Waste Authority's (DSWA) landfills for disposal. Hundreds of thousands of dollars are spent annually in tipping fees. Results of the sweeper waste monitoring program are helping us to explore alternative means of dealing with the large quantity of wastes collected that are more environmentally friendly and less costly than taking the materials to landfills. These include recycling through soil remediation companies. We explored potential use of sifted sweeper wastes for clean cover at DSWA landfills. However, the high levels of petroleum hydrocarbons typically measured in this material (>1000 mg/Kg) preclude this.

Street waste disposal and utilization practices around the country are quite varied. Ordinances, laws and guidelines governing solid waste disposal often do not address street waste handling and disposal, making compliance difficult. Urban street sweepings contain large amounts of potentially reusable materials, such as sand and gravel. Depending on the season, they may also contain large amounts of organic debris. Interest is increasing in alternative treatment and reuse of sweepings (Florida DEP, 2004; Brinkmann et al., 1999; Liebens, 2001; Townsend et al., 2002). Everyone's goal, ultimately, is to find ways to treat, dispose of or reuse these wastes that are economical, preserve resources and protect human health and the environment.

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Table 1. Summary of chemical analyses of sweeper wastes at Chapman Road maintenance yard, June 10, 2003.

Parameter	Units	Sifted Pile mean ± std. err.	Unsifted Pile mean ± std. err.
Inorganics:			
Aluminum	mg/Kg	6378 ± 833.8	7736 ± 396.2
Antimony	mg/Kg	7.04 ± 2.64	3.44 ± 1.10
Arsenic	mg/Kg	3.6 ± 0.7	6.14 ± 1.29
Barium	mg/Kg	107.08 ± 17.23	78.72 ± 6.01
Beryllium	mg/Kg	ND	ND
Cadmium	mg/Kg	0.662 ± 0.221	0.396 ± 0.060
Calcium	mg/Kg	32864 ± 7073.6	16188 ± 6124.4
Chromium	mg/Kg	255.12 ± 99.45	112.66 ± 41.58
Cobalt	mg/Kg	9.4 ± 1.7	7.42 ± 0.25
Copper	mg/Kg	69.44 ± 10.58	58.08 ± 8.17
Iron	mg/Kg	30540 ± 6762.1	25960 ± 3667.0
Lead	mg/Kg	78.52 ± 20.15	83.02 ± 20.41
Magnesium	mg/Kg	20216 ± 6905.6	10086 ± 3204.5
Manganese	mg/Kg	917.8 ± 393.1	681 ± 184.3
Mercury	mg/Kg	0.092 ± 0.016	0.168 ± 0.0408
Nickel	mg/Kg	150.88 ± 57.1	56.02 ± 8.24
Potassium	mg/Kg	416.5 ± 5.4	557.2 ± 138.3
Selenium	mg/Kg	3.06 ± 0.73	2.36 ± 0.39
Silver	mg/Kg	1.92 ± 0.28	1.9 ± 0.40
Sodium	mg/Kg	1330.2 ± 630.1	847.2 ± 156.6
Thallium	mg/Kg	1.274 ± 0.582	0.696 ± 0.009
Vanadium	mg/Kg	37.36 ± 7.24	35.74 ± 2.12
Zinc	mg/Kg	201.6 ± 43.2	213.4 ± 28.9
Chloride	mg/Kg	1110 ± 746	824 ± 138
Volatiles:			
Methyl Acetate	µg/Kg	7620 ± 1942	1006 ± 114.3
Semivolatiles:			
Acenaphthene	µg/Kg	ND	ND
Acenaphthylene	µg/Kg	ND	ND
Anthracene	µg/Kg	141.3 ± 75.5	ND
Benzo(a)anthracene	µg/Kg	505 ± 162	372 ± 130
Benzo(a)pyrene	µg/Kg	541 ± 162	374 ± 131
Benzo(b)fluoranthene	µg/Kg	609 ± 147	434 ± 156
Benzo(g,h,I)perylene	µg/Kg	ND	ND
Benzo(k)fluoranthene	µg/Kg	535 ± 164	366 ± 124
Chrysene	µg/Kg	693 ± 171	451 ± 157
Dibenz(a,h)anthracene	µg/Kg	ND	ND
Fluoranthene	µg/Kg	1714 ± 512	1117 ± 411
Fluorene	µg/Kg	ND	ND
Indeno(1,2,3-cd)pyrene	µg/Kg	181 ± 65.2	ND
Naphthalene	µg/Kg	ND	ND
Phenanthrene	µg/Kg	883 ± 315	737 ± 319
Pyrene	µg/Kg	948 ± 239	576 ± 200
Butylbenzylphthalate	µg/Kg	277 ± 151	ND
bis(2-Ethylhexyl)phthalate	µg/Kg	1270 ± 430	773 ± 368
Di-n-octylphthalate	µg/Kg	193 ± 102	ND
Di-n-butylphthalate	µg/Kg	ND	192 ± 59.3
Nutrients			
Ammonia Nitrogen	mg/kg	211 ± 13	162 ± 15.2
Total Kjeldahl Nitrogen	mg/kg	652 ± 99.2	797 ± 53.1
Total Phosphorus as P	mg/kg	290 31.6	395 ± 32.4
Nitrite	mg/kg	ND	0.8 ± 0.2
Nitrate	mg/kg	5.3 ± 1.9	1.3 ± 0.2
Ortho-phosphate	mg/kg	ND	ND

Table 2. Summary of leachability analyses of sweeper wastes at Chapman Road maintenance yard, April 6, 2005.

	Units	Composite Range
TPH	mg/Kg	3410 - 8020
BTEX	mg/Kg	ND
PCBs	mg/Kg	ND
Total Organic Halogen	mg/Kg	ND
TCLP Metals		
As	mg/L	ND – 0.12
Ba	mg/L	0.91 – 1.0
Cd	mg/L	ND
Cr	mg/L	ND
Pb	mg/L	ND – 1.4
Hg	mg/L	0.002 – 0.12
Se	mg/L	ND
Ag	mg/L	ND
TCLP Semivolatiles	mg/L	ND
TCLP Pesticides	mg/L	ND
TCLP Herbicides	mg/L	ND
TCLP Volatiles	mg/L	ND

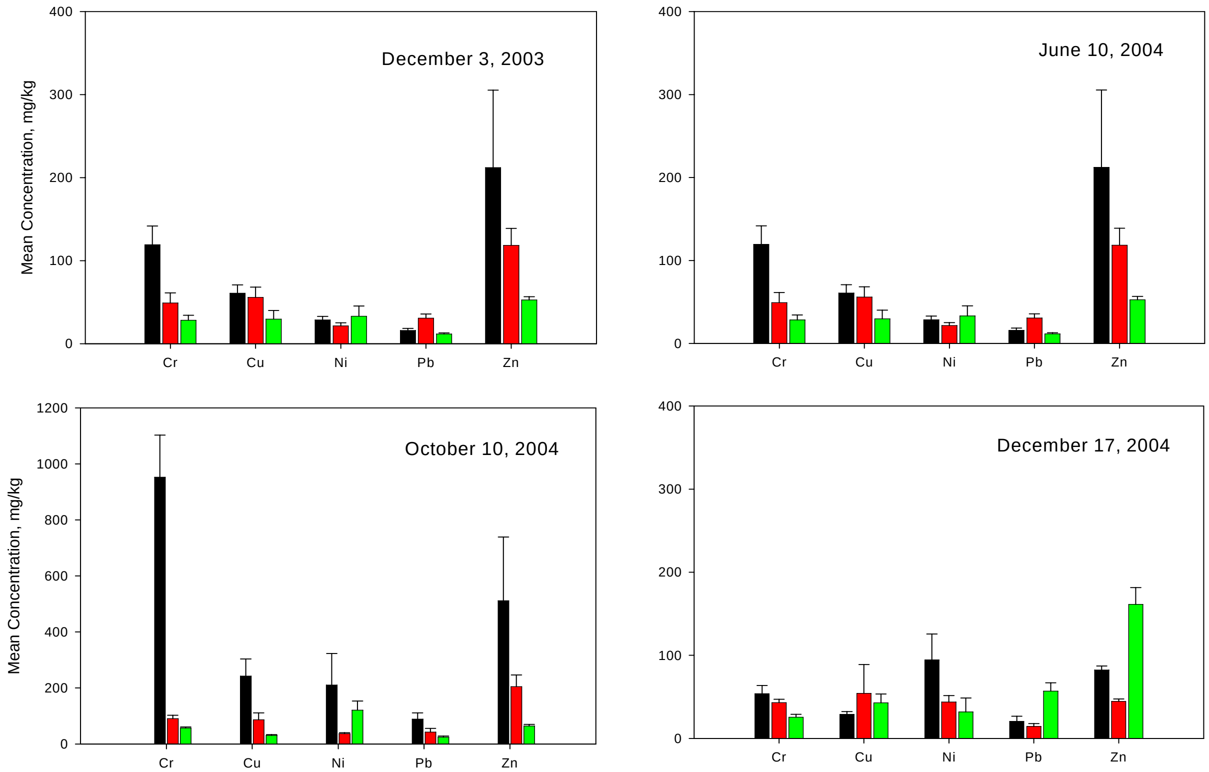
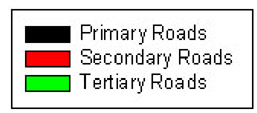


Figure 1. Analyses of heavy metals in regenerative air street sweeper wastes by road type. Note different scale on October plot.



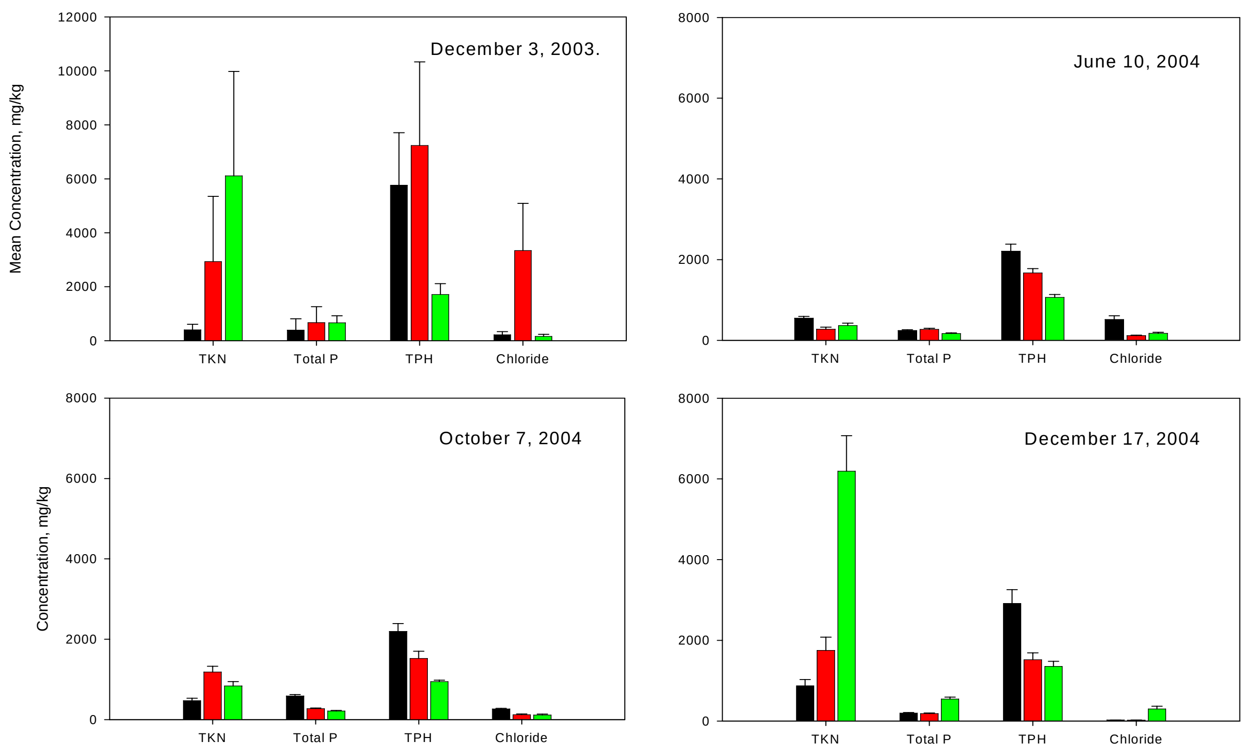


Figure 2. Analyses of nutrients, petroleum hydrocarbons, and chloride in regenerative air street sweeper wastes by road type. Note different scale on December 2003 plot.